GOATS 2008
Autonomous, Adaptive Multistatic Acoustic Sensing

PI: Henrik Schmidt
Massachusetts Institute of Technology
77 Massachusetts Avenue
Room 5-204
Cambridge, MA 02139
Phone: (617) 253-5727 Fax: (617) 253-2350 Email: henrik@mit.edu

CoPI: John J. Leonard
Massachusetts Institute of Technology
77 Massachusetts Avenue
Room 5-214
Cambridge, MA 02139
Phone: (617) 253-5305 Fax: (617) 253-8125 Email: jleonard@mit.edu

CoPI:Arjuna Balasuriya
Massachusetts Institute of Technology
77 Massachusetts Avenue
Room 5-211
Cambridge, MA 02139
Phone: (617) 324-1461 Fax: (617) 253-2350 Email: dbattle@mit.edu

Award Number: N00014-08-1-0013

LONG-TERM GOALS

To develop net-centric, autonomous underwater vehicle sensing concepts for littoral MCM and ASW, exploiting collaborative and environmentally adaptive, bi- and multi-static, passive and active sonar configurations for concurrent detection, classification and localization of subsea and bottom objects..

OBJECTIVES

GOATS-2008 is a continuation of the interdisciplinary research program GOATS, initiated in 1998 in collaboration between MIT and NURC, and as such a seamles continuation of the research effort under the previous grant N00014-05-1-0255. The principal opjective is to develop, implement and demonstrate real-time, onboard *integrated acoustic sensing, signal processing and platform control* algorithms for adaptive, collaborative, multiplatform REA, MCM, and ASW in unknown and unmapped littoral environments with uncertain navigation and communication infrastructure.

A rellated objective is the development of a nested, distributed command and control architecture that enables individual network nodes of clusters of nodes to complete the mission objectives, including target detection, classification, localization and tracking (DCLT), fully autonomously with no or limited communication with the network operators. The need for such a nested, autonomous communication, command and control architecture has become clear from the series of experiments

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2008	**Annual**	**00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE
GOATS 2008 Autonomous, Adaptive Multistatic Acoustic Sensing

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Massachusetts Institute of Technology,77 Massachusetts Avenue, Room 5-204,Cambridge,MA,02139

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
code 1 only

14. ABSTRACT
To develop net-centric, autonomous underwater vehicle sensing concepts for littoral MCM and ASW, exploiting collaborative and environmentally adaptive, bi- and multi-static, passive and active sonar configurations for concurrent detection, classification and localization of subsea and bottom objects..

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**12**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

carried out in the past under GOATS and several recent experiments carried out under the UPS PLUSNet program.

APPROACH

The GOATS (Generic Ocean Array Technology Sonar) research program is a highly interdisciplinary effort, involving experiments, theory and model development in advanced acoustics, signal processing, and robotics. The center-piece of the research effort has been a series of Joint Research Projects (JRP) with SACLANTCEN. The joint effort was initiated with the GOATS' 98 pilot experiment [1] and continued with the GOATS’ 2000 and BP02/MASAI02 experiments. Currently the collaboration is being continued under a NURC JRP on sensing network technology. In addition to the field experiments involving significant resources provided by NURC, GOATS uses modeling and simulation to explore the potential of autonomous underwater vehicle networks as platforms for new sonar concepts exploring the full 3-D acoustic environment of shallow water (SW) and very shallow water (VSW).

The fundamental approach of GOATS is the development of the concept of a network of AUVs as an array of *Virtual Sensors*, based on fully *integrated sensing, modeling and control*, reducing the inter-platform communication requirements to be consistent with the reality of shallow water acoustic communication in regard to low bit-rate, latency and intermittency. Thus, for example the past GOATS effort has demonstrated that platform motion information can be used for clutter control by providing geometric constrains to on-board detection algorithms, reducing the communication requirements to location, POD, and classification information. Conversely, on-board sensor fusion and processing can be fed back to the vehicle control system for autonomous, adaptive sampling – again with the potential for significantly enhanced POD/PFA performance.

In regards to applications to MCM, GOATS explores the use of bi-static and multi-static Synthetic Aperture created by the network, in combination with low frequency (1-10 kHz) wide-beam insonification to provide coverage, bottom penetration and location resolution for concurrent detection, localization and classification of proud and buried targets in SW and VSW. The signal processing effort is therefore centered around generalizing SAS processing to bi-static and multi-static configurations, including bi-static generalizations of auto-focusing and track-before-detect (TBD) algorithms. Another issue concerns the stability and coherence of surface and seabed multiples and their potential use in advanced low-frequency SAS concepts.

More recently, the GOATS effort has transitioned towards the development of similar, autonomous network concepts for passive littoral surveillance, e.g. the Undersea Persistent Surveillance (UPS) program, initiated in 2005 and completed in 2008. PI Schmidt was lead PI and Chief Scientist for the UPS PLUSNet Program, which developed a network concept of operations based on clusters of AUV and gliders, connected via acoustic communication, and intermittent RF communication with the operators through periodically surfacing gliders. A prototype network concept with a hybrid, cooperating suite of underwater and surface assets was successfully demonstrated in PN07 in Dabob Bay, WA. The MIT UPS effort is curretly being transitioned into the ONR PLUS INP. As in the past GOATS effort, the MIT marine autonomy effort is utilizing the open-source MOOS control mission control software originally developed and funded under GOATS. However, in contrast to past experiments where all platforms were controlled and piloted by MIT, the PLUSNet concept demonstrated the feasibility of ahybrid suite of diverse network nodes, with significant native, proprietary, software infrastructure. To take advantage of the robustness of the native control software,

while at the same time retaining the flexibility in regard to sensor-driven adaptivity and collaboration, MIT, and in turn PLUSNet, has adopted a new nested control architecture, where the lower level control of the nodes, as well as the overall field control can be performed using arbitrary third-party software, while the medium level, adaptive and collaborative control of the nodes and the clusters is performed within the MOOS software framework.

Such a nested command and control infrastructure with heterogeneous assets invariably need translation to and from a common communications protocol. Starting with the MB'06 experiment, MIT and Bluefin AUVs were controlled using a new, so-called “back-seat driver” paradigm wherein low-level commands to the Bluefin control software were translated and conveyed by a specially designed MOOS module.

The mid-level, adaptive and collaborative control of the network nodes is carried out using MOOS in combination with the new multi-objective, behavior-based IvP control framework developed within MOOS by Michael Benjamin at NUWC/MIT. The core of this architecture consists of a behavior-based control system which uses multiple objective functions to determine the appropriate course, speed, and depth of the platform at every control cycle (typically 10-20 Hz). The desired course of action is determined by computing a multi-function optimization over the objective functions using the Interval Programming Model developed by Benjamin [2] which provides a very fast optimization suitable for small vehicles.

The development of GOATS concepts, including PLUSNet, is based heavily on simulation, incorporating and integrating high-fidelity acoustic modeling, platform dynamics and network communication and control. In regard to the environmental acoustic modeling, MIT continues to develop the OASES-3d modeling framework for target scattering and reverberation in shallow ocean waveguides. As has been the case for the autonomous command and control, recent emphasis has been towards the simulation of passive DCLT by the PLUSnet network. As was previously the case for the MCM effort, the approach has been to develop a complete system simulation capability, where complex adaptive and collaborative sensing missions can be simulated using state-of-the-art, high-fidelity acoustic models for generating synthetic sensor signals in real time. As in the past, this has been achieved by linking the real-time MOOS simulator with the SEALAB acoustic simulation framework, which in ‘real-time’generates element-level timeseries using Green’s functions using legacy environmental acoustic models such as OASES, CSNAP, and RAM. This new unique simulation environment allows for full simulation of adaptive DCLT missions for the MIT/Bluefin AUVs towing hydrophone arrays, incorporating correlated and directional ambient noise, and signals generated by moving surface ships and targets

WORK COMPLETED

GLINT08 Experiment, Pianosa, Italy, July-Aug. 2008

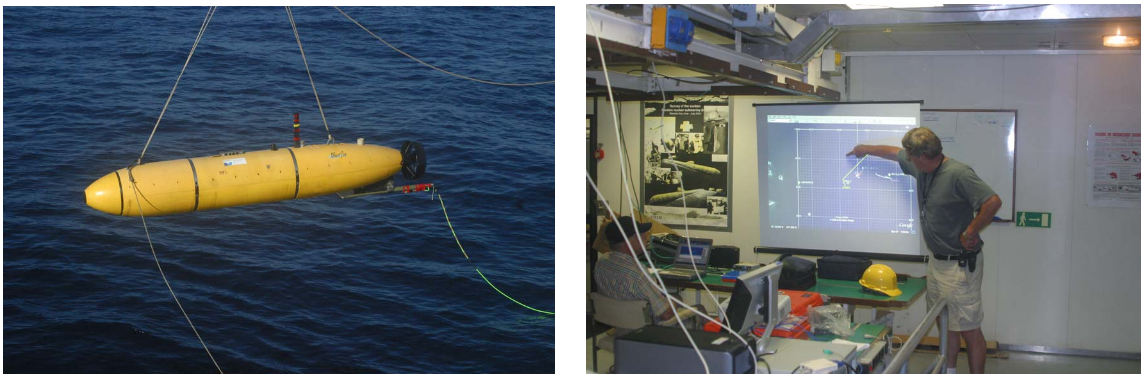

Figure 1. GLINT08 Experiment, Pianosa, Italy, July-Aug. 2008. Left frame shows Unicorn BF21 AUV with towed DURIP array being deployed from NRV Alliance. Right frame shows command and control center on NRV Alliance with situational display.

As part of a Joint Research Project (JRP) on undersea sensing network technology (NURC project 4G4), MIT in collaboration with NURC, WHOI, NUWC and several Italian organizations, carried out a major field demonstration of a hybrid undersea sensing network. The experiments had several scientific objectives, relating both to the sensing concepts, communication networking, and distributed, autonomous control.

The principal objective was do demonstrate the commmunication, command and control of a hibrid platform suite, using a common communication infrastructure based on the WHOI Micromodem and Compact Control Language (CCL), and a common autonomy system for operating all mobile and fixed assets, based on the ASTM F41 proposed 'backseat driver' standard and the MOOS-IvP behavior-based autonomy software suite. The ASTM F41 architecture places the higher level autonomy in the payload, fully integrated with the sensing and onboard processing, while the lower level vehicle control and navigation is performed by the native control software ('frontseat driver', responding to simple commands for desired speed, heading and depth, and responding back to the payload autonomy ('backseat driver'). The architecture, developed largely funded under the past GOATS effort at MIT, had previously been intergrated and demonstrated on the SCOUT kayaks, the Bluefin BF21 AUVs, and several land robots at MIT. In preparation for and during GLINT08, it was succesfully integrated into the NURC OEX AUV and the NUWC IVER-2 AUVs, both deployed in the experiment towing hydrophone arrays for multistatic acoustics. In addition the architecture was partially integrated into the NUWC FOLAGA environmental sampler and two b ottom moorings equipped with micromodems for uncdersea networking. The hybrid network with these assets is shown schematically in Figure 2.

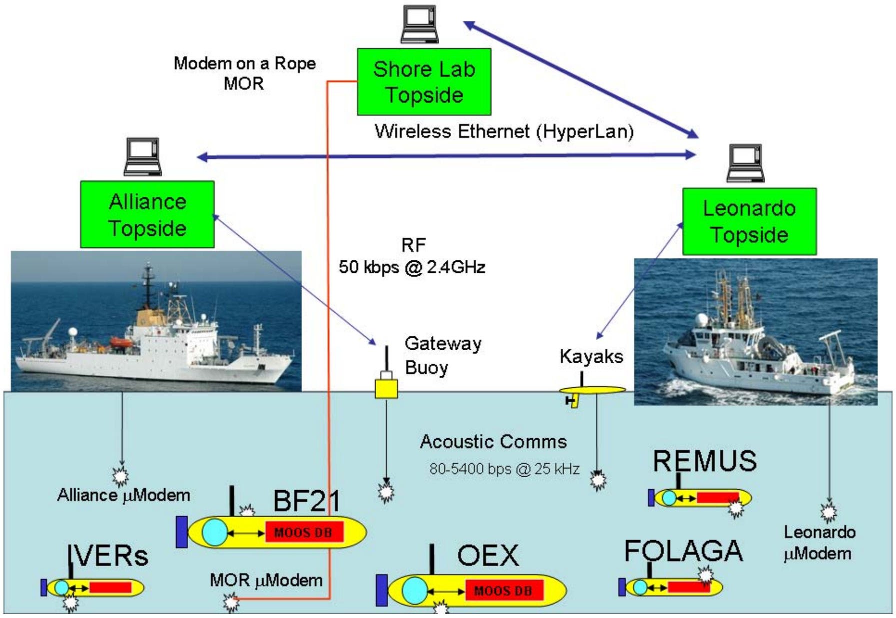

Figure 2. GLINT08 hybrid vehicle and communication networking.

The principal scientific objective og GLINT08 was to collect a comprehensive multi-static active dataset using 3 AUVs with towed hydrophone arrays, which will support the development of robust multi-static active processing approaches suited for operation in the limited computational environment of AUVs. The three vehicles were the NURC OEX with the 48-element SLITA array, the MIT Unicorn BF21 with the 32-element DURIP array, and the NUWC IVER-2 vehicle towing a 16-element hydrophone array. The two large vehicles, the OEX and Unicorn, had fully integrated MOOS-IvP autonomy systems early in thye experiment and were routinely used in coordinated data collection missions. On the last day of the experiment, all three array-towing vehicles were operated together. Also, the MOOS-IvP/CCL communication infrastructure allowed several demonstrations to be performed of fully autonomous obstacle and collision avoidance by Unicorn and OEX, as illustrated in Fig. 3, which shows the topside real-time situational display, which graphically displays all status and contact information transmitted from the vehicles via the undersea communication network.

With the Unicorn BF21 AUV fully integrated with the MOOS-IvP autonomy and CCL communication, as developed in past experiments MB06, MINUS07, and PN07, it was operated with less personnel than previously required. Significant effort went into streamlining and automating operating procedures so that more effort could be spent focusing on the scientific goals. Thus, once initially deployed, the vehicles are entirely commanded using the CCL message set, including redeployments, target prosecute behaviors, and return to base commands. This additional infrastructure will carry over to future experiments, including the upcoming SWAMSI09 and GLINT09 experiments.

In addition, a major accomplishment in GLINT08 was the development of an enhanced report and command structure which allows for dynamic, optimally compressed, coding and decoding of the messages. This new Dynamic CCL (DCCL) communication handler was implemented in MOOS-Ivp and demonstrated for real-time interleaved transmission of egular low-bandwidth FSK messages with high-rate PSK coded messages, with up to 2kbyte messages at 5.4kb/s, allowing for real-time

transmission of CTD measurements and array signal processing products such as Beam-Time Records (BTR) for real-time display on the topside situational display. It is believed that the real-time topside display of BTR data from an AUV has not previously been achieved in the field. Acoustic communications messages from Unicorn and the other AUVs were assimilated with a heterogeneous mixture of other data sources (AIS, ship's NMEA, etc) to give a unified situational display available to both the science crew and the ship's captain, as illustrated in the left frame of Figure 3. The left frame shows an example of the usefulness of the situational display in a case of a run-away of one of the NUWC IVER-2 AUVs. The last reported navigation for the vehicles were extrapolated in the topside command center to determine a possible grounding site on the island of Pianosa. The workboat was subsequently sent to the predicted site at the northern tip, and the vehicle was recovered from the rocks within 10 m of the predicted location..

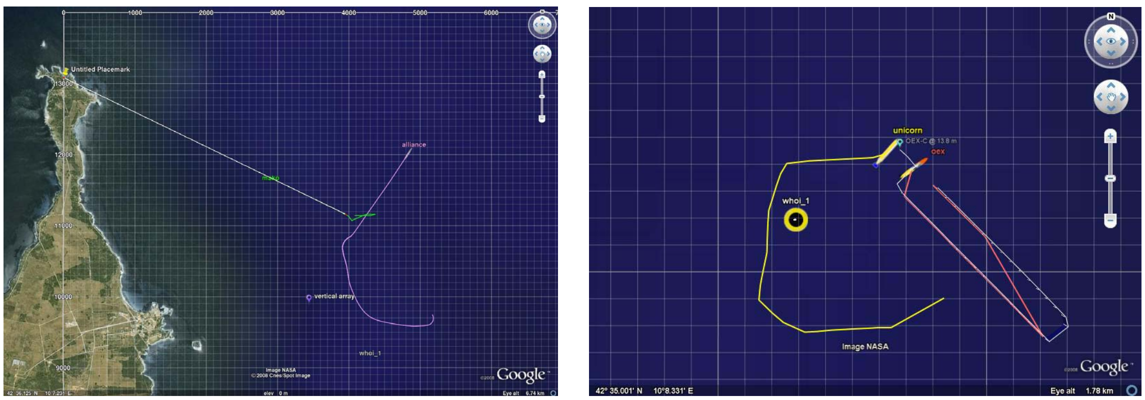

Figure 3. Real-time topside situational display in GLINT08 command center onboard NRV Alliance. The left frame shows extrapolation of navigation data for runaway IVER-2 vehicle. The right frame shows the topside rendering of a Unicorn performing its obstacle avoidence and collision avoidance behaviors, with the WHOI Gateway buoy and the OEX AUV, respectively.

GLINT '08 Multi-Static Signal Processing & Tracking

Several multi-static tests were successfully carried out during the experiment. Specifically, they were conducted on Aug 4th, Aug 6th to 7th and Aug 10th to 11th. The following assets were deployed during the tests.

- NRV Alliance - deploying an active acoustic source
- CRV Leonardo - deploying an echo-repeater to simulate a target for active acoustic source insonification
- Unicorn AUV - towing the DURIP array for multi-static acoustic data collection
- OEX AUV - towing the SLITA array for multi-static acoustic data collection

In addition to the acoustic data, all the navigational data of the assets were also collected and compiled. Figure 4 illustrates one particular test carried out on Aug 7th. Here, the trajectories of the Alliance and Leonardo are depicted in magenta and green respectively. Alliance was left drifting with occasional maneuvers. Leonardo was drifting initially, but was later deployed to move eastward to facilitate

Doppler data collection. The trajectories of the Unicorn & OEX are shown in yellow and red respectively. Both the AUVs were deployed to run in a race track manner.

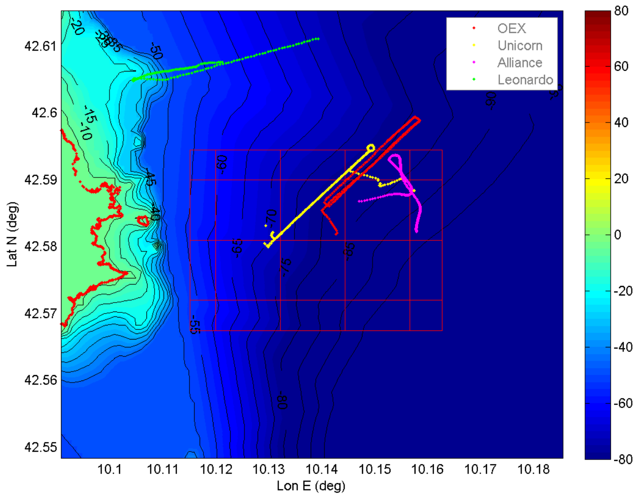

Figure 4: GLINT '08 platform trajectories on Aug 7th, 11:44:58 to 14:08:28

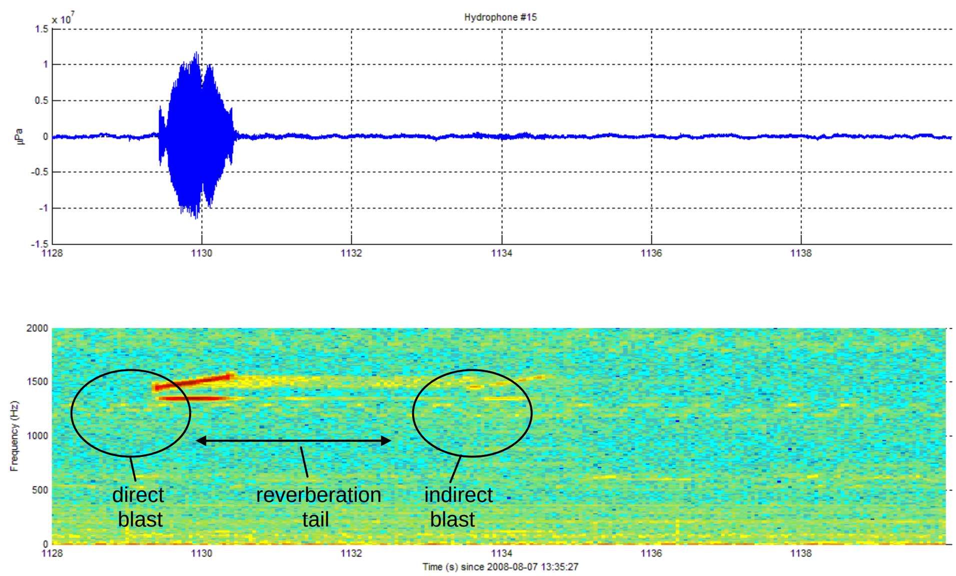

Figure 5: Time-series and spectrogram from a single hydrophone of the DURIP array

Following the experiment, the multi-static data were processed and analyzed. Figure 5 shows the time-series and spectrogram obtained from a single hydrophone of the DURIP array. Clearly, we see the HFM and CW pulses - direct and indirect blasts, and the long reverberation tail.

Specifically, one run collected a very clean data set to test algorithms for passive source ranging. Another run collected data for depth discrimination using the "depth-averaged submergence index". This data set is unique in that a manned submarine or surface vessel would not be able to perform the rapid depth and pitch changes that were required by Unicorn to collect the data.

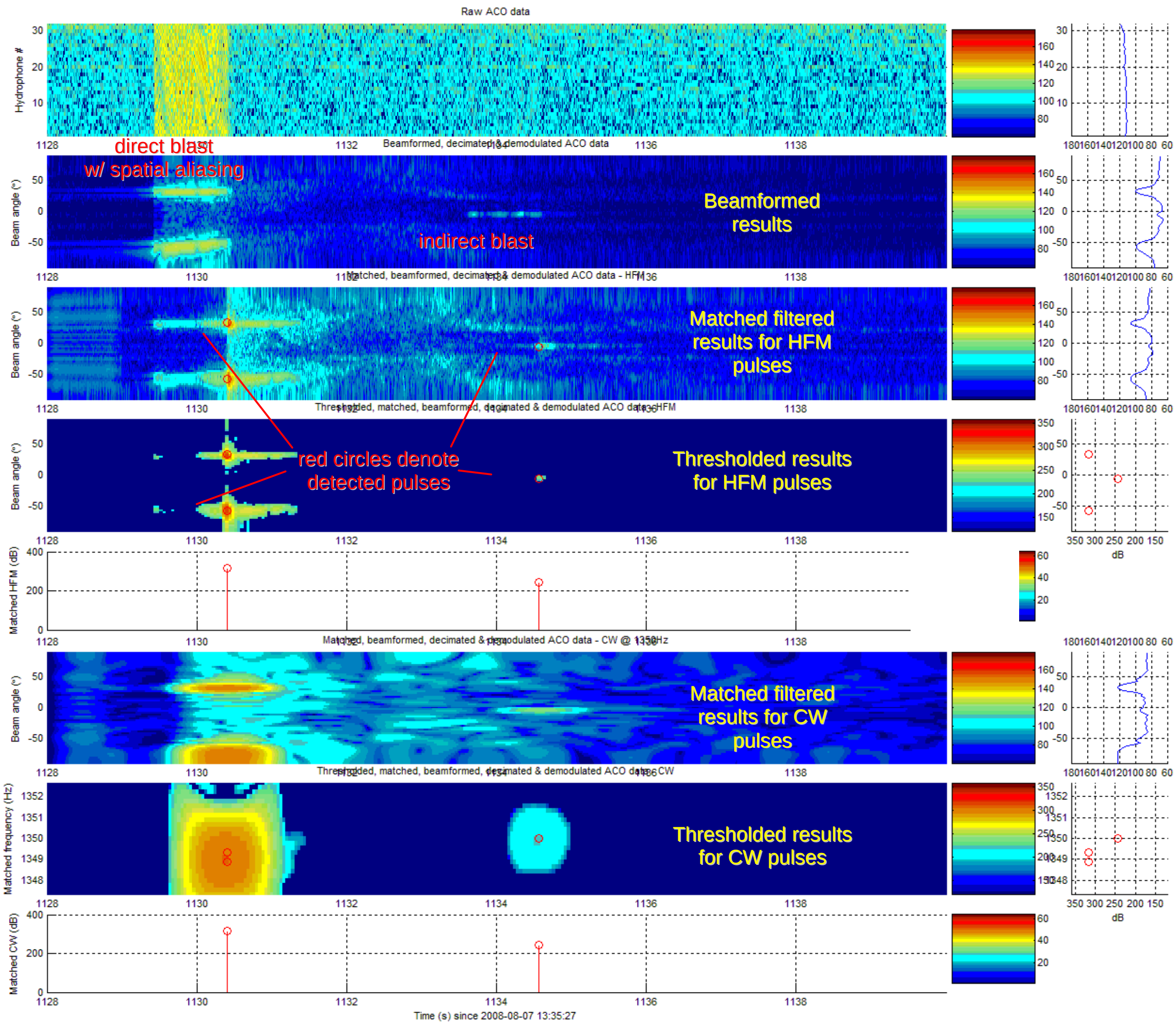

Figure 6: Multi-static signal processing

RESULTS

Figure 6 depicts the results obtained with the multi-static signal processing chain. Evidently, we see the directions-of-arrival (DOAs) of the direct and indirect blasts in the beamformed data. Due to the low sampling frequency of 4000Hz, we observe spatial aliasing occurring. By matched filtering and thresholding the beamformed data, we obtain peaks that provide the times-of-arrival (TOAs), DOAs and Doppler frequencies of both the HFM and CW pulses as shown in Figure 7.

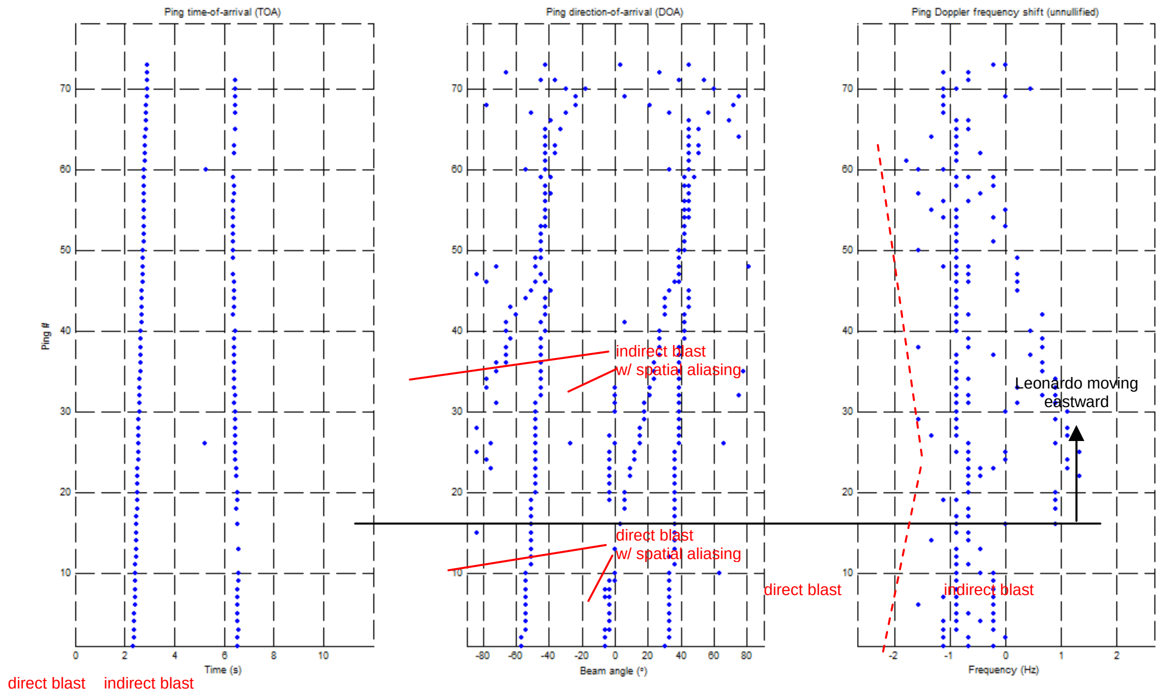

Figure 7: GLINT08 Multistatic tracking of simulated, moving target (CRV Leonardo)

The analysis of the data reveiled a few issues which must be addressed before the next deployment. The non-acoustic sensors in the DURIP array were faulty and we are not able to obtain the heading, pitch and depth information of the array. Presently in the signal processing, we have assumed that the heading of the array corresponded to that of the AUV, which is not an accurate assumption in reality. To alleviate this problem, it is necessary to incorporate some means of estimating the array dynamics within the signal processing chain.

Apparently, not all the acoustic and navigational data were time-synchronized accurately. This is particularly the case for the Unicorn and DURIP array. Although efforts were made during the experiment to log down the respective times and match them to UTC time, we still observe time skewing across different recording media.

GLINT08 Passive acoustic ranging experiments

Preliminary results indicate that the data collected will be extremely useful in determining the practicality of algorithms proposed for passive ranging and depth-discrimination. For example a comprehensive data set was collected for supporting the research into development of new methods for source ranging, which are suitable for implementation in a real-time AUV environment. The AUV Unicorn was towing its array at various depths on a linear track, readially away and towards from the flextensional source deployed from CRV Leonardo. Figures 8 and 9 clearly show the striations in the range-dependent spectrograms achieved from the towed array data, as predicted by the waveguide invariant. In theory, the angles of the striations can be used to determine the range to the acoustic source. While it is easy for a human to see the striations, getting a computer on an AUV to perform this task robustly is obviously non-trivial, in particular in more challenging noise and clutter environments.

The GLINT08 data provide a solid baseline for the future analysis, and for testing the robustness of candidate algorithms.

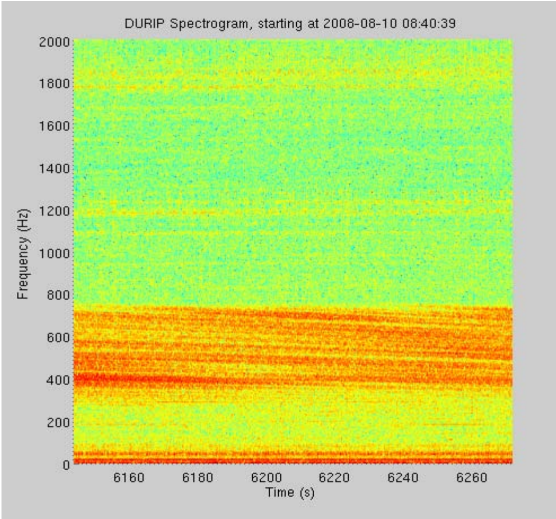

Figure 8: Spectrogram from the towed array while Unicorn was moving towards the acoustic source.

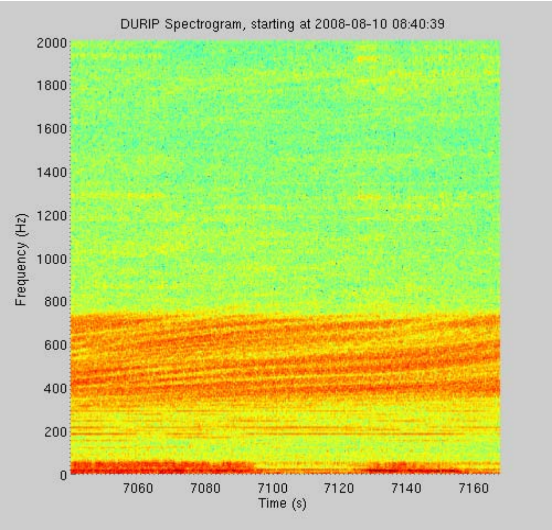

Figure 9: Spectrogram from the towed array while Unicorn was moving away from the acoustic source.

IMPACT/APPLICATIONS

The long-term impact of this effort is the development of new sonar concepts for MCM and ASW, which take optimum advantage of the mobility, autonomy and adaptiveness of an autonomous, cooperating vehicle network. For example, bi- and multi-static, low-frequency sonar configurations are being explored for completely or partially proud or buried mines in shallow water, with the traditional high-resolution acoustic imaging being replaced by a 3-D acoustic field characterization as a combined detection and classification paradigm, exploring spatial and temporal characteristics which uniquely define the target and the reverberation environment. Similarly, platform mobility and collaboration is being explored for enhancing DCLT performance of littoral surveillance networks such as PLUSNet.

TRANSITIONS

The GOATS'2005 program is a seamless continuation of the now completing GOATS'2005 effort. The progress made in autonomous, multi-AUV, net-centric control, navigation, communication, and collaborative sensing and its implementation into the MOOS-IvP autonomy system architecture, has been transitioned into the ASAP-MURI and the now completed Undersea Persistent Surveillance (UPS) PLUSNet effort for which PI Schmidt was Lead-=PI and Chief Scientist.

Further, the MOOS-IvP software architecture (MOOS was originally developed by P. Newman under GOATS funding in 2002) is being transitioned to the ONR UCII program, as well ast the new PLUS INP distributed surveillance program, where it has been chosen at the autonomy system baseline, from which it will be be developed into a restricted or classified MOOS-IvP+ software repository, established in collaboration between NUWC and MIT Lincoln Laboratories.

Finally, MOOS-IvP is being transitioned to handle the Mission Planning and Control of both moving and fixed assets in the NSF ORION Ocean Observatories. Thus MIT is partner in the UCSD led team charged with developing the Cyber Infrastructure for ORION, with responsibility for the MP&C.

The seismo-acoustic models developed by MIT are being maintained and dissiminated under the GOATS grant. The OASES and CSNAP environmental acoustic modeling codes are used extensively in the ONR sponsored r5esearch at MIT, and continue to be maintained, expanded and made available to the community. The latest addition is a 3D version of CSNAP, which efficiently provides wave-theory solutions for propagation and scattering around seamounts. OASES and CSNAP is continuously being exported or downloaded from the OASES web site, and used extensively by the community as a reference model for ocean seismo acoustics in general. (http://acoustics.mit.edu/arctic0/henrik/www/oases.html) Among the new transitions to applied Navy programs, the OASES and CSNAP framework is being used extensively by several contractors such including Lockheed-Martin, BBN, Northrop-Grumman, and SAIC., and Navy laboratories, including NUWC, NURC, CSS, and NRL.

RELATED PROJECTS

This effort has constituted part of the US component of the GOATS`2000 Joint Research Project (JRP) with the SACLANT Undersea Research Centre, and is currently collaborating with NURC under the Autonomous Sensing Networks Joint Research Projects (JRP). The MIT GOATS effort has been funded jointly by ONR codes 321OA (Livingston), 321OE (Swean,Curtin), and 321TS (Johnson/Loeffler/Commander).

The GOATS program developed out of the ONR Autonomous Ocean Sampling Network (AOSN) initiative completed in FY00, and is strongly related to the continuing AOSN effort. GOATS is also directly related to the Shallow Water Autonomous Mine Sensing Initiative (SWAMSI), initiated in FY04, and currently continuing, and of which MIT is a partner.

The adaptive command and control architecture and acoustic modeling capabilities developed under GOATS are being applied in several other related programs MIT is partnering in, including the AREA (Adaptive Rapid Environmental Assesment) component of the now completed ONR “Capturing Uncertainty” DRI, aimed at mitigating the effect of sonar performance uncertainty associated with environmental uncertainty by adaptively deploying environmental assesment resources. The cooperative AUV behavior progress together with the AREA concept is being currently transitioned into the ASAP MURI and the Undersea Persistent Surveillance (UPS) program, with experimental demonstrations in Monterrey Bay in MB06 and in Dabob Bay, WA in PN07.

The OASES modeling framework, which is being maintained, upgraded, and distributed to the community under this award, has been used intensively in all the related programs MIT is participating in. The new 3D model of propagation over seamounts [3] is being transitioned and applied to the analysis of the experimental results obtained at Kermit seamount under the NPAL program.

REFERENCES

1. Schmidt, H., Maguer, A, Bovio, E., Fox, W.L.J., LePage, K., Pace, N.G., Hollett,R., Guerrini, P., Sletner, P.A., Michelozzi, E., Moran, B. and Grieve, R. "GOATS'98 – AUV Network Sonar Concepts for Shallow Water Mine Countermeasures," *SACLANT Undersea Research Centre*, Report SR-302, 1998. pdf

2. M. R. Benjamin, "Interval Programming: A Multi-Objective Optimization Model for Autonomous Vehicle Control," Ph.D. dissertation, Brown University, Providence, RI, May 2002.

3. W. Luo, "Three-Dimensional Propagation and Scattering around a Conical Seamount," Ph.D. thesis, MIT, 2007

PUBLICATIONS

W. Luo, "Three-Dimensional Propagation and Scattering around a Conical Seamount," Ph.D. thesis, MIT, 2007
W. Luo and H. Schmidt, "Three-Dimensional Propagation and Scattering around a Conical Seamount," Accepted for publication in *J. Acoust. Soc. of Am.*, 2008 .

H. Schmidt, D.P. Eickstedt, A.P. Balasuriya, D. Battle, M.R. Benjamin, *Nested Autonomy – A Concept of Operations for Distributed, Undersea Acoustic Surveillance*, to appear in the U.S. Navy Journal of Underwater Acoustics (Unclassified), Apr. 2009.

K. Cockrell, H. Schmidt, "Source localization and tracking in a waveguide via sequential bayesian estimation (A)" *J. Acoust. Soc. Am.* **123** 3339 (2008)

A. Balasuriya, H. Schmidt, M.B. Benjamin, "Integrated sensing, modeling, and control in undersea sensor networks (A)", *J. Acoust. Soc. Am.* **123** 3007 (2008)

H. Schmidt, K.D. Lepage, "Propagation, scattering and reverberation in an ice-covered Arctic ocean (A)", *J. Acoust. Soc. Am.* **123** 2989 (2008)

Wang, D., P.F.J. Lermusiaux, P.J. Haley Jr., D. Eickstedt, W.G. Leslie and H. Schmidt, 2008. Acoustically Focused Adaptive Sampling and On-board Routing for Marine Rapid Environmental Assessment. Journal of Marine Research. [In Press, refereed]

A. Bahr, J. Leonard. Cooperative Localization for Autonomous Underwater Vehicles. Accepted for publication in the International Journal of Robotics Research, 2008.

A. Bahr and J. Leonard. Minimizing Trilateration Errors in the Presence of Uncertain Landmark Positions. In European Conference on Mobile Robotics, Freiberg, September, 2007

M. Parra-Orlandoni - "Target Tracking Onboard an Autonomous Underwater Vehicle: Determining Optimal Towed Array Heading in an Anisotropic Noise Field", MS 9/07

D. Wang - "Autonomous Underwater Vehicle (AUV) Path Planning and Adaptive On-board Routing for Adaptive Rapid Environmental Assessment", Ph.D 9/07